RECENT EARTHQUAKES.[1]

UNTIL recent years the attitude of the ordinary Englishman with regard to earthquakes has been one of apathy. He argued that, although every year 30,000 earthquakes might occur in the world, his country only contributed about half a dozen, and these, because they were so small, did more to excite curiosity than to create alarm. Although in 1883 Colchester, and in 1896 Hereford, lost a few chimney pots, and buildings were unroofed, also at intervals, reckoned by one or two hundred years, London has been shaken, still England could not be regarded as an earthquake-producing country. British-made earthquakes may be of rare occurrence, but should there be any relief of seismic strain similar to that of 1883 or 1896 in the synclinal on which our great metropolis stands, we might find as many chimney pots in the streets as there are inhabitants. A suggestion of this kind, however, does not disturb the mind of our ordinary Englishman. Hints respecting the possible instability of his country produce no effect, and he fails to see why he or his Government should be called upon to support seismological investigations. Recent earthquakes have, however, modified his opinion, and although England may be free from earthquakes, he finds he has to insure against and pay for the effects which these disturbances have caused in distant places. By observations on what has stood and what has been destroyed after violent shakings of the ground, and as the result of investigations together with elaborate and costly experiments carried out entirely in Japan, not only have new methods of construction been formulated, but these have had extensive applications. Experience has shown that the new types of buildings stand whilst the old ones are shattered. At the present moment, Valparaiso, San Francisco, Kingston, and very many other cities, towns, and villages, not only in America, but also in Europe and Asia, have by recent earthquakes been reduced to heaps of débris. When these are reconstructed, it is extremely likely that the well-tested rules and methods, the outcome of applied seismology, will not be neglected.

Seismological investigations have been made, not only for scientific reasons, but to minimise the loss of life and property. In connection with the destruction of San Francisco alone, we are told that British insurance companies are called upon to meet claims amounting to 12,000,000*l.*, while losses of like character may have to be met in other parts of the world. The Englishman living on his own little patch of *terra firma* is continually paying for earthquake effects all over the world. The thinking man now realises that insurance rates in many countries must vary with the seismicity of a district, together with the character of the structures to which they refer. Sub-oceanic seismic activity frequently results in the failure of cables. It is therefore of extreme importance that the sites of these submarine disturbances should be located (see map). In these and in many other ways it is easy to show that England has probably a greater practical interest in the results of seismological investigation than any other country. Finance and earthquake effects are close relations. Another incentive to the removal of apathy in regard to seismology lies in the fact that the mind of the public, like that of the individual, becomes fatigued by repetition. What is asked for is something new, and, if possible, it should be sensational. Newspapers and magazines do all they can to relieve this craving, with the result that the public is liberally supplied with stories about big catastrophes and deductions based thereon. A new *hors d'oeuvre* has been added to the daily scientific menu, and the halfpenny paper and the sixpenny magazines have given a stimulus to investigations bearing upon earth physics.

In countries where earthquakes have been severe, and where by their frequency they are continually forcing them-

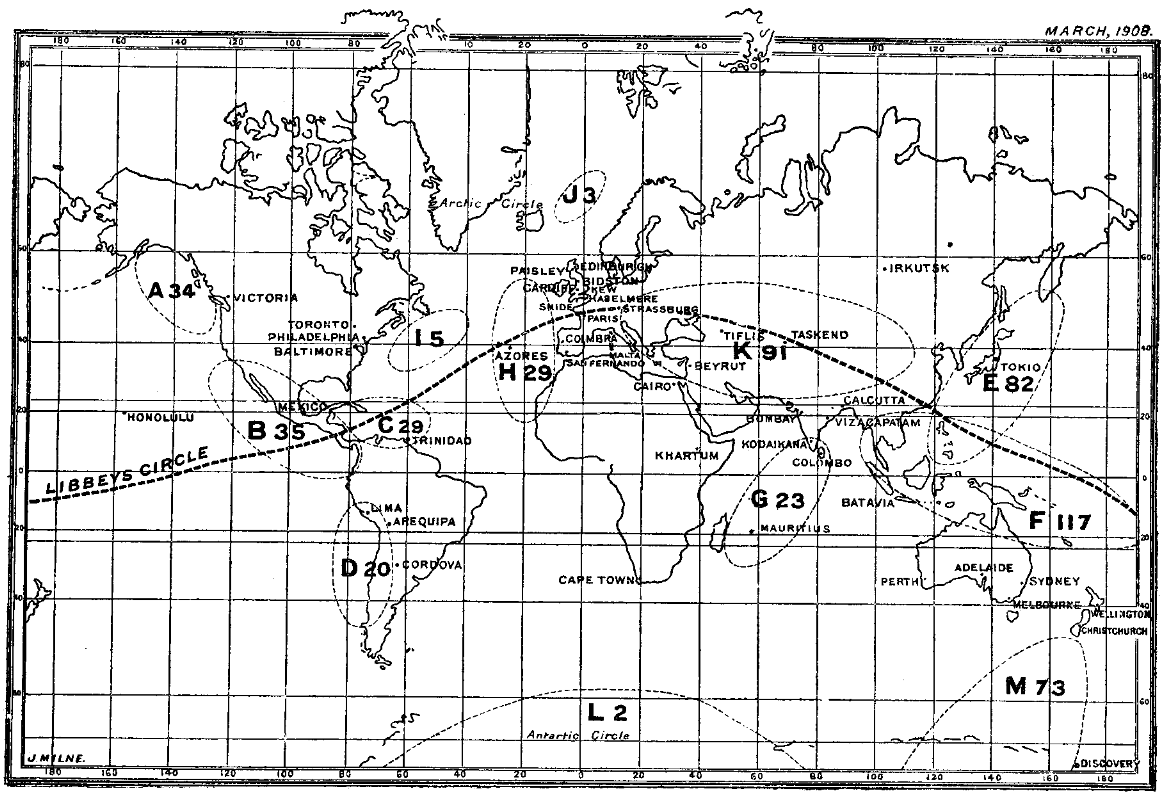

FIG. 1.—Stations in cooperation with the British Association working with similar instruments (Milne pendulum). Number of world-shaking earthquakes since 1899 which have originated in districts marked A, B, C, &c., are indicated.

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[1] Discourse delivered at the Royal Institution on Friday, March 20, by Prof. J. Milne, F.R.S.

selves upon public attention, a desire to investigate is furnished by the earth itself. Chili is now arranging to have a system of observing stations. Jamaica is speaking about the same, whilst the United States are extending what they now possess. Three recent earthquakes have awakened three different Governments to the fact that, although schoolmasters may not flog their children, nature is not always as indulgent to its people. Japan, in addition to establishing stations in Formosa, Saghalin, China, and Korea, has already more than 1000 observing stations, 120 of which have instruments for recording local shocks. For seismological investigations the Government of that country annually allocates 1000*l.* to 5000*l.*, and this is outside expenditure in connection with the chair of seismology, and concomitant with investigations of earthquakes in foreign countries. During the last ten or twelve years Japan has issued about seventy quarto volumes bearing upon seismological investigations. Russia has a series of well-equipped stations within its borders. For very many years Italy has given great attention to the movements of the ground. These are recorded at several hundreds of stations, 160 of which are provided with instruments. Austria, Germany, and many other States are also devoting great attention particularly to the collection of earthquake statistics. I fail, however, to see that these statistics, which are necessarily imperfect, will pass beyond the borderland of local interest. So far as I am aware, all foreign stations are subsidised by their respective Governments. Great Britain enjoys the cooperation of forty-five stations provided with similar instruments, which are distributed fairly evenly over the four quarters of the world. The names and positions of these stations are shown upon the accompanying map (Fig. 1). The home stations are supported by the British Association, the Royal Society, the *Daily Mail*, Mr. M. H. Gray, and other private individuals. So far as the recording of world-shaking earthquakes is concerned, I believe the British cooperation to be, at the present time, quite equal to a combination of the stations of all other countries. The last outcome in connection with observational seismology has been the establishment of an International Seismological Association. The central bureau is in Strassburg, its president is Prof. A. Schuster, and its general meetings take place once every four years. I am not aware that France has formally announced its adherence. The British Government, by subscribing 160*l.* a year to the central bureau, has accepted a shelter from a Continental ægis. For nearly fifty years the British Association has encouraged seismological research, but whatever prestige it may have gained, together with its attendant commercial and other advantages, these are passing under a new *régime* across the Channel.

A Government of a country does not wish to seek abroad for an explanation why telegraphic messages have ceased to flow. To confirm, extend, or disprove a cablegram, a Government, a business house, or the public of a given country would like to obtain information within its own boundaries. When a country or a colony finds itself cut off from the outside world in consequence of cable interruption, that country or colony, together with other countries, would like to have a ready means of saying whether the interruption had been due to submarine disturbances or to some other operation, as, for example, war. Those who lay cables would prefer to have information as to positions of suboceanic sites of seismic activity from records made in their own country rather than those which had been made abroad. When after great convulsions cities have to be rebuilt, and there are many at the present moment, it is natural that information bearing upon reconstruction to reduce earthquake effects would be sought for at the world's central office, and those who supply information would in all probability supply engineers and material. Insurance companies who wish to apportion rates to risks when insuring against earthquake effects might also think it best to seek their information at a central bureau. After an earthquake, when such companies are called upon to pay the insured, many difficult questions arise which can only be answered by seismograms. Millions of pounds sterling are dependent upon these records, and it is therefore important that the same should be readily accessible. A seismogram, which travels quicker than a telegram, may affect the Stock Exchange. We no more require a central bureau to discuss applied seismology than we do to discuss the construction of torpedoes or flying machines.

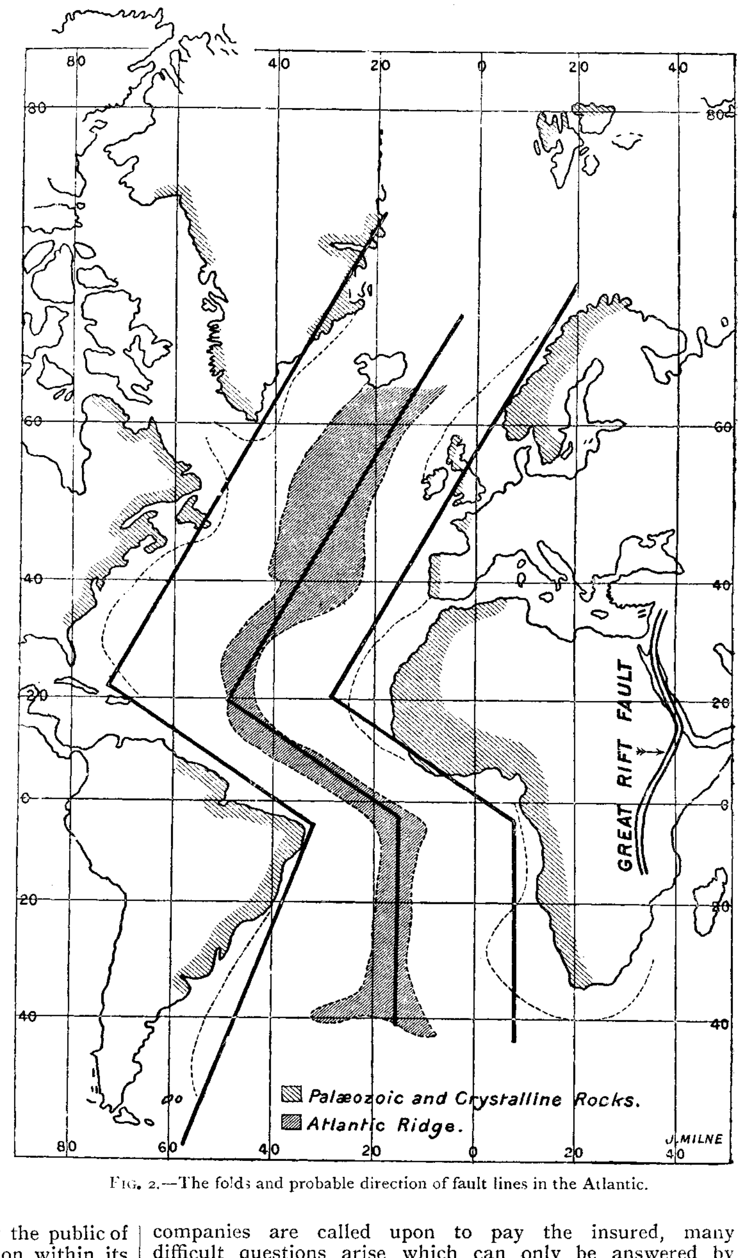

Fig. 2.—The folds and probable direction of fault lines in the Atlantic.

A discovery which, during the last few years, has done much to popularise seismology is the fact that a very large earthquake originating in any one part of the world may be recorded in any other portion of the same. This means that the opportunity for carrying on seismological research is not a monopoly enjoyed only by those who reside in earthquake countries. Although only a few persons in Great Britain have been privileged to feel one of its home-made tremors, every one of its inhabitants is very many times per year moved by earthquakes. Back and forth motion of the ground is performed too slowly for us to feel, while, if there is a movement like the swell upon an ocean, the undulations are too long and flat for us to see.

Waves start out from their epicentral area, which is a district that has been fissured and shattered by the formation or extension of large faults in all directions. Observation, however, shows that these waves are propagated farthest in one particular direction. For example, the chief movement following the San Francisco earthquake, which originated from fault lines running parallel to the coast of California, was much more marked in countries lying to the east or west of California than in countries lying towards the south. England and Japan obtained large records of the disturbance, while in Argentina the records were extremely small. In the case of the Jamaica earthquake, where the lines of origin ran east and west, the phenomenon was reversed. Toronto received a large quantity of motion, and England a very little. Another peculiarity of this phase of earthquake motion is that it may be propagated in one direction round the world to a greater distance than in an opposite direction. The suggestion is that the initial impulse was delivered in the direction towards which motion was propagated farthest. If for illustration we assume that the slip on a fault line has been downwards towards the east, then the motion would travel towards the east farther than it would towards the west. That which happens corresponds to what we see if we dip the blade of a spade in water and suddenly push the blade in some particular direction. The water waves thus created travel farthest in the direction of the impulse.

Another curious phenomenon connected with the large waves of certain earthquakes is that they can pass their equatorial or quadrantal region unobserved. They may be very marked for 1000 miles round their origin, and recordable, but much reduced in size, about their antipodes, but not recordable in between. For example, an earthquake originating near New Zealand may be recorded in that country, but not in India, Egypt, West Asia, or east of Europe, though in Britain it may make itself evident by the thickening of a photographic trace. The phenomenon may be compared to a water wave running down an expanding estuary. At the mouth of such an estuary it may have become so flat that it is no longer recognisable. Should it, however, run up a second estuary, we can imagine concentration taking place, so that near the top of the second estuary it would eventually become instrumentally recordable. In these antipodean survivors we see the final efforts of a dying earthquake. It is only occasionally that the precursors and the followers of these large waves have sufficient energy to reach their antipodes. They die *en route*. The former, notwithstanding their comparative feebleness, because they throw considerable light upon the internal constitution of our earth, are the most interesting feature in a seismogram. They are of two kinds, a first phase and a second phase. These are usually regarded as compressional and distortional modes of wave propagation. The large waves are probably quasi-elastic gravitational waves, something like an ocean swell, which travel round the world with a constant velocity of about 3 km. per sec., causing continental surfaces to rise and fall like huge rafts upon a heaving ocean. The precursors behave quite differently. Phase i. may commence with a velocity of 3 km. or 4 km. per sec., but as the length of the wave-path increases this quickly rises to 10 km., and thence to a maximum of 12 km. per sec. These paths are assumed to be along chords, and so long as these chords do not lie at a depth greater than twenty or thirty miles, the speeds are such as we should expect to find in materials like those composing the outer surface of our earth. These waves, therefore, indicate a thickness for the earth's crust comparable to thicknesses which have been arrived at by other lines of argument. The rapid approximation to uniform speed suggests that below a depth of twenty or thirty miles we enter a nucleus which is very rigid and fairly homogeneous. The second phase waves, up to a distance of 120° from their origin, have a speed of about 6 km. per sec. For longer paths, Mr. R. D. Oldham points out that their velocity is apparently suddenly reduced. He seeks for an explanation of this by postulating the existence of a central core in the earth where waves are retarded and refracted, with the result that the wave-paths no longer follow chords. These waves may, therefore, emerge on the surface of the earth after having passed relatively to their starting point on the farther side of its centre. Whether we do or do not accept this central core, it is clear that the new seismology has added in a very marked manner to the knowledge we formerly possessed respecting the interior of the globe upon which we live. Our ideas respecting its homogeneity and its great rigidity have been changed by seismological investigations.

When large earth waves sweep round the world, it is found that at particular stations magnetic and electrometer needles have been disturbed. Magnetometers, when installed at Toronto, do not appear to have responded to the slow undulations of the earth's surface, while the same instruments, after being removed to Agincourt, only ten miles distant, are now affected. The inference from this and observations in other parts of the world is that the movements, rather than being caused mechanically, may be due to the disturbance of some adjacent magnetic magma. If this is the case, then at particular stations where the movements due to teleseisms correspond with unusual disturbance of magnetic needles, inasmuch as a magnetic magma is denser than common rock, at these stations the value for g should be higher than that which would be anticipated. For certain stations this appears to be the case.

Another series of investigations which may widen our knowledge respecting conditions and operations beneath our feet are based upon the light effects which have been so frequently observed at the time of large earthquakes. Accounts of luminosity in the heavens and on hills as accompaniments to large earthquakes are common. At the time of the Valparaiso earthquake, August 17, 1906, the attention of very many people was attracted to lights which appeared upon the hills. Captain Taylor, of the R.M.S. *Orissa*, compared these to chain lightning, which extended as far as the eye could reach. An acquaintance of mine, Mr. G. E. Naylor, of Valparaiso, told me that he saw the lights repeatedly, and they took place immediately before a shock, there being only a fraction of a second of time between the two. He described them as having a bluish tinge; to others, however, they appeared yellowish. An ordinary explanation for these appearances is that they are due to the rubbing together of rock surfaces or the discharge of frictionally produced electricity. These observations suggest that with a megaseismic collapse, not only do we get mechanical disturbances which pass through and over the surface of the world, but that part of the initial energy at the origin is converted into some other form of energy, which possibly may find a response at very distant places. This latter transmission would, however, take place with a velocity comparable with that of light. If anything of this sort has a real existence, seismologists may hope to record earthquakes at the moment they take place. This consideration, and the observation that from time to time a quarry in the Isle of Wight, known as Pan Chalk Pit, appeared to me to be luminous, suggested the possibility of hypogenic activities giving evidence of their existence in the form of light. Pan Pit faces north, and in winter it is not reached by the sun. Its glowings apparently rise and fall in intensity, and are most noticeable after a dull, damp day. The experiments I made were as follows:—at the end of a chamber twenty yards from the mouth of a tunnel driven into the chalk, a hole about 2 feet square was excavated. Into this a box with a light-proof door was cemented. The back of the box, which touched the chalk, was made of zinc. In the zinc three holes of different sizes were made along a vertical line. A cylindrical drum, covered with bromide paper and driven by clockwork, was brought up to within one-eighth of an inch from these holes. A rim on the bottom part of the drum had a clearance given to it by cutting a horizontal slit in the zinc plate beneath the holes. Neither the drum, the paper, nor the rim touched the zinc plate or the chalk. The rate of movement of the paper was 90 mm. per day. A small electric lamp moved about outside the box produced no effect upon the paper inside. A self-recording thermometer and a hygrometer showed that the temperature and the moisture in the chamber were practically constant. A similar piece of apparatus was installed at a depth of 160 feet in the King Edward Mine, Camborne, Cornwall. These experiments were commenced at Pan Chalk Pit in February, 1903, and were continued for four months. They were taken up again in the middle of August, 1906, and lasted eight months. A sheet of paper on development was frequently quite clear, but at times it was partly or entirely marked with dark bands, black lines, round black spots, or semi-circular spots along the lower edges. At Shide the dark bands have not been numerous, but they occurred on nearly all the sheets from Camborne. In certain cases we appear to have three bands, the positions of which apparently coincide with the three holes in the zinc plate. In some of these bands there are hard black lines broken along their length and made up of black spots.

The black spots vary in diameter from a fraction of a millimetre to 8 millimetres. In the centres of some of these there is a small white or brownish spot. As pointed out by Mr. W. H. Bullock, of Newport, these closely resemble spots which can be produced on bromide paper by a tiny electric spark. During a week we may have either no spots, one spot, or a hundred spots. The semi-circular spots, which I have called singeings, are found on the lower edge of the paper where the brass cylinder joins the aluminium rim. There may be two or three of these per week, whilst at other times they occur at intervals of about half an hour. As only ten black spots occurred at the time of large earthquakes, we can only regard these as coincidences. Neither dark bands, spots, nor singeings appear to be connected, beyond what I have mentioned, with any particular meteorological conditions. Neither is there any reason for supposing that these effects are due to radio-activity. If a piece of bromide paper is sealed up in a black envelope, and another piece is placed in a black envelope which has a thin glass window, and these are laid on a surface of chalk, the glass window touching the same, say, for a period of several days, it was found after development that one piece of paper showed the image of the window, whilst the other had only stains, which might be attributed to dampness. With the object of determining whether micro-organisms played any part in the phenomena observed, my friend Dr. R. C. Brown, of Parkhurst, has made cultures from scrapings from the surface of the chalk before which my cylinder was exposed. Cultures were also made from scrapings taken from the open chalk. Micro-organisms were found in both. These have been exposed to a moving photographic surface similar to that used in the pit, but they gave no evidence of luminosity. The conclusion for the present is that the luminosity occasionally seen at Pan Pit may result from a very feeble brush or glow-like electrical discharge. If this be the case, it would also account for the bands on the photographic paper, the other markings being due to minute sparks. Moreover, if this is so, and we assume that silent electrical adjustments have a real existence, it is difficult to escape the conclusion that these must have an effect on what we call "climate," and hence upon everything that lives upon the surface of the globe. We have many instances of places only separated by a few miles, as, for example, Newport and Sandown in the Isle of Wight, or Bournemouth and Swanage, the climates of which are said to be very different. The thermometer, barometer, and hygrometer do not explain these differences; the only apparent difference between such places appears to be one of soil and the moisture in the same. Inasmuch as we find great differences in the emanations from granite, clayslate, and chalk, it would seem extremely probable that we should find differences in the relative electrical conditions of different soils.

To determine whether earthquakes are increasing or decreasing, it is not only necessary to turn over the pages of many histories, but also to consult the geologist. Jules Verne might perhaps have dipped deeper into time than a geologist or physicist, and drawn pictures of the reactionary effect which might accompany the collision of one world with another, bombardments of great meteorites, a click that announced the birth of our moon, the sudden yieldings of a primitive crust covering an ocean of molten rock, and of many other things that float through the brains of those who entertain us with the results of their imaginations. The greater number of earthquakes, and certainly all that are large, originate from the formation or extension of faults. These operations have been most marked when secular movement amongst rock masses is in progress, as, for example, during the growth of mountains. Should this be in operation near large bodies of waters, volcanoes and earthquakes are found in the same region. If, therefore, we wish to know when earthquake frequency and intensity was at a maximum, we turn to those periods in geological history when mountain ranges were built, when volcanic activity was pronounced, and when great faults were made. The first of these periods would be coincident with the creation of the Urals, the Grampians, and other ancient mountain ranges. This took place in Palæozoic times. Another period of mountain formation was in early Tertiary times, when the Himalayas and the Alps were slowly, but intermittently, brought into existence. In both these periods volcanic activity was pronounced, and beds of coal were formed. When the crust of the earth was crumbling, mountains grew spasmodically, faults gave rise to earthquakes, volcanic forces found their vents, and conditions existed which gave rise to the accumulation of materials to form coal.

In quite recent times, many large faults have been created at the time of earthquakes. In 1891 the Mino-Owori fault was created in central Japan, 10,000 people lost their lives, and 128,000 buildings were destroyed. On April 18, 1906, San Francisco and other towns were ruined by movements along a fault which can be traced for a distance of 200 miles. One estimate suggests that it may be 400 miles in length. The largest fault which has been created in extremely recent geological times seems to be the Great Rift Valley of Central Africa. We are told that it commences in the south near Lake Nyassa, passes northward through Tanganyika, the great lakes of Central Africa, branches north-eastward towards Lake Rudolph, up the Red Sea, through Akaba to the Jordan Valley, a distance of 4000 miles. In certain districts it shows itself as a strip of country let down between two parallel fractures. It has been compared to the cracks which can be seen in the moon. If we accept this as a reality, we have only to imagine this Great Rift fault to be extended as regards its length and breadth, and we have a trough in many respects similar to that which holds, not thirty lakes, but the waters of the Atlantic. If we look at the Atlantic, either as shown on a Mercator's chart or on a globe, we notice the complementary resemblances between the contours of the old world and the new. Then, if we draw a line down the submerged backbone of this ocean, we see that this is the reflection of the European and North African western coast line (Fig. 2). Next, if these old-world contours are pushed westwards towards this median line, while the contours of the two Americas are pushed eastwards, we find that one approximately fits in with the other. The fit becomes more marked if we bring together the submerged edges of continental shelves or lines representing the general direction of the opposing coast lines. Another point not to be overlooked is that the rock formations on the west side of the Atlantic are very similar to those in the same latitude on the eastern side. It is as if we had a street with the shops on one side of it exactly similar to those on the other side. In northern Spitsbergen, and again in Greenland, we find a large development of crystalline and Palæozoic rocks, and these continue southwards through Labrador, Newfoundland, Maine, and then through the Alleghanies. They again appear in Brazil as far south as Monte Video. On the eastern frontier of the Atlantic, from Scandinavia through Scotland and Ireland, Wales, western France, and western Africa as far as Cape Town, we see a replica of the two Americas. The Atlantic is a canal, the opposing banks of which are symmetrical in form and geological material. An idea, but one which is not very probable, which this suggests is that at some very early period in the world's history two Rift Valleys, one parallel to the eastern submerged backbone of the Atlantic, and the other parallel to its western frontier, were formed. Separation subsequently took place along these faults, and these, under the influence of surface and underground activities, have continually increased. If, then, the Atlantic had an origin due to Rift Valley formation rather than to folding or contraction, then the greatest earthquake in the history of the world may have taken place when east became east and west became west, and our world was cracked from pole to pole.

Just as the frequency of earthquakes has fluctuated during geological time, similar fluctuations have taken place during historical time. In central Japan earthquake frequency had a maximum in the ninth century, and since that time, century after century, violent shakings have become less and less. In January, 1844, at Comrie, in Perthshire, twelve earthquakes were recorded. Now there may not be one per annum. At the present time, in consequence of the destruction of several large cities, the popular idea is that earthquakes are on the increase. As a matter of fact, the world as an earthquake-producing machine has a steady output. On the average, about sixty very large disturbances are recorded, and the greater number of these, fortunately for humanity, have their origins beneath ocean beds or in sparsely inhabited regions. In addition to these megaseismic efforts, it is estimated that about 30,000 small earthquakes take place per year, England's annual contribution to this number being about half a dozen. If we had records like these extending backwards through several ages, we might readily estimate the time when seismic activity would cease. When this ceases, rock folding will also cease, and the degrading processes resulting in surface denudation will be unopposed. Bit by bit land areas will be reduced to sea-level, and the habitable surfaces, as we now see them, will be no more.

An interesting observation bearing upon megaseismic frequency is found in the analyses of registers relating to the North Pacific. On the west side of that ocean seismic frequency is greatest in the summer, while on the east side it is greatest in the winter. An explanation for this is sought for in the seasonal alteration in the flow of ocean currents, the oscillations of sea-level, and changes in the direction of barometric gradients, which phenomena are interrelated. In summer, off the coast of Japan, the Black Stream runs perhaps 500 miles farther north than it does in winter, while Dr. Omori points out that, although barometric pressure may on the Japan side of the Pacific be low in summer, this decrease in load is more than compensated for by the increased height of ocean-level; the inference is that the pressure on the ocean bed is greater in summer than in winter, and this is the time of the greatest seismic frequency.

Another factor bearing upon earthquake frequency may perhaps be found in the change in position of the earth's pole. A chart showing the path of the earth's north pole indicates that its movements are by no means always uniform. Although at times these may be nearly circular, it also shows sharp changes in the direction of its motion. It has even been retrograde. If on a chart showing these pole displacements we mark the time positions of world-shaking earthquakes, it is seen that these are grouped round the sharper bends of the pole-path. World-shaking earthquakes have, in fact, been most numerous when the pole-path has deviated farthest from its mean position. The observations embrace a period of thirteen years, during which 750 large earthquakes were recorded. Although these earthquakes represent large mass displacements, it is not supposed that they would be sufficient to produce the observed pole movement. The pole movement, however, may have given relief to seismic strain, or both effects may arise from some common cause.

Mass displacements accompanying a megaseismic effort must, however, tend to produce some pole displacement, and thus set up strains. From time to time these should find relief in the weaker portions of the earth's crust. Large earthquakes should therefore occur in pairs, triplets, or in groups, after which we should expect a period of quiescence. This idea is due to the Rev. H. V. Gill, S.J. I find that the British Association registers lend considerable support to the hypothesis. The author of the idea, however, goes a step farther, and points out that if all matter within our globe or that which constitutes its crust was equally free to move, the secondary displacement should, with regard to the earth's axis of rotation, be symmetrically located in regard to the position of the primary disturbance. Out of 126 large earthquakes recorded between 1899 and 1905, I find that twenty of these appear as ten pairs, the members of each pair being in symmetrically located districts. This may or may not have been a matter of chance. The observation that a marked relief of seismic strain in one part of the world has frequently been followed by a smaller relief in some distant region also suggests the idea that earthquake begets earthquake. In my own mind the relationship of earthquake to earthquake has been fairly well demonstrated, but to place the matter beyond the borderland of doubt large earthquakes must be compared in regard to space and time with their kind, with small earthquakes, and with volcanic eruptions. All the volcanic eruptions of the West Indies have closely followed on the heels of great earthquakes which have originated, not in the West Indies, but on the neighbouring coasts of Central and South America. One general inference is that the faultings and freckles on the face of our world should have a distribution as symmetrically disposed as wrinkles are on the face of an elderly person.

Already when speaking about the length of faults which have been created at the time of large earthquakes, we have indicated at least one dimension of the earth block which has been disturbed. For instance, the earth block which was disturbed at the time of the San Francisco earthquake may have had a length of 400 miles; its breadth might be determined by the width of the country which had been broken up by branching and parallel faults. Harboe suggests that in a meizoseismic area hidden faults may be assumed to exist along lines drawn half-way between pairs of groups of places which have been struck at about the same time. R. D. Oldham attributes the Assam earthquake of 1897 to the sudden shifting of 10,000 square miles of territory over a thrust plain. The molar displacement determined by the method suggested by Harboe would be that 50,000 square miles had been disturbed. The fact that so many earthquakes shake the whole world, or will agitate an ocean like the Pacific for many hours, indicates that the initial impulse must have been delivered over a large area, or that sudden alterations have taken place in the contour of ocean beds. With regard to the magnitude of the latter changes, we have learnt much from cable engineers, who have given us many instances where cables lying in parallel lines, ten or fifteen miles apart, have been simultaneously interrupted and ocean depths over considerable areas have been increased. The depth to which these large faults extend is a matter of inference. We may well imagine them as passing through the whole thickness of the earth's crust, and the displaced block falling to give up its energy to a nucleus which we know transmits undulatory movements all over our globe with uniform velocity. If we take this crust to be thirty miles in thickness, then with Harboe's area for the superficial disturbance, the block which was disturbed at the time of the Assam earthquake would be represented by 1½ million cubic miles.

Following the initial impulse of a large earthquake, it frequently happens a few minutes later that a second severe movement is felt. In Japan this is popularly spoken of as the Yuri Kaishi, or the return shaking. This may be a second yielding within the disturbed district, but from its resemblance to the main shock it suggests an echo-like reflection. If we drop a bullet into a large tub of water, waves travel outwards to the sides of the tub, where they are reflected, and converge at the centre from which they set out. With the earthquake waves, the reflecting surface may be represented by the roots of mountain ranges. If these are at varying distances from the origin the reflected waves would give rise to complications at the focus. The transmitting medium for these waves I take to be the more or less homogeneous material which lies beneath the heterogeneous crust of our world. This transmits large waves with a constant velocity. In the case of the Californian earthquake, which originated on fault lines on the western side of that country, I should imagine the reflecting surface to be the Sierras, 200 miles distant. The wave group would travel to these mountains and back in about four minutes, and this is approximately the time interval between the two first large wave groups in seismograms I have of that disturbance. After the first echo or echoes, an earthquake usually dies out as a series of surgings which frequently have a striking similarity to each other. One explanation of these rhythmical recurring groups is that they simply represent times when the movement of the ground has synchronised with the natural period of the recording instrument. Although the terminal vibrations seen on a seismogram may be attributed to this cause, it does not exclude the idea that rhythmical beats at an origin may result in rhythmical responses at a distance.

Side-issues of seismology are quite as instructive as the information we derive from the records of earthquakes. We have already referred to light effects which accompany large earthquakes. This, as we have seen, led up to investigations connected with micro-organisms. A long series of experiments, which commenced in Japan and were continued in the Isle of Wight, involved a series of investigations bearing upon the transpiration of plants. The fundamental object of these experiments was to determine whether valleys always retained the same form. Did they open and shut? To answer the question I set up on the two sides of a valley horizontal pendulums identical with those which are used to record teleseismic motion. These instruments, which are by photographic means self-recording, are exceedingly sensitive to small changes in level. What I found was that on fine days the booms of these instruments moved in opposite directions, each away from the bed of the valley. At night the motions were reversed, and the booms moved towards each other, that is, towards the bottom of the valley. Several instruments were employed, and the records were confirmed by the movements of the bubbles of sensitive levels. During the day the records indicated that the sides of the valley opened, and at night they closed. The two valleys I worked upon behaved like ordinary flowers, they opened when the sun was shining and closed at night. The best explanation I can offer is that the phenomenon is largely dependent upon the transpiration of plants. This is marked during the day, but not at night. On a bright day a sunflower or a cabbage may discharge 2 lb. of aqueous vapour. A square yard of grass will give off 10 lb. or 12 lb. The result of this is that during the day underground drainage has not received its full supply of water to load the bottom of the valley. At night time, when plants' transpiration is reduced, subsurface drainage is increased, and the load at the bottom of the valley is also increased. Therefore, at night the bottom of a valley, in consequence of its increased water load, is depressed, and this is accompanied by a closing of its sides. During the day the load runs off, and the valley opens. This may also explain why soak wells in valleys and streams carry less water during the day than they do at night, and at the same time it suggests that the side of a valley is a bad place for an observatory. Every day as the world turns before the sun, lamp-posts and tall structures salute the same, whilst many valleys open. At night time these movements are reversed.

One phenomenon which accompanies all large earthquakes, which, however, has never yet received the attention it deserves, is the influence which great disasters have exercised upon the emotions. Immediately after the Kingston earthquake, we read of the dazed and almost insane condition of the people. Many were affected with an outburst of religious ecstasy, thinking the last day had come. The negro population camped on the racecourse, and spent their time in singing hymns. Somewhat similar scenes took place in Chili; men and women ran hither and thither, mad with terror and devoid of reason. Amid shrieks and sobs, and the wailing of a multitude, an "Ora pro Nobis" or a "Pater Noster" might now and then be heard. In early civilisations underground thunderings have so far excited the imagination that subterranean monsters or personages have been conjured into existence, and these in many instances have played a part in primitive religions. At the time of an earthquake in Japan, the children are told that the shaking is due to the movement of a fish which is buried beneath their country, and in Japan we find references to this fish in the pictorial art, glyptic art, literature, and everyday conversation, all of which would be unintelligible if we did not know the story of the earthquake fish. In other countries the subterranean creature will be a pig, a tortoise, an elephant, or some other animal. The most interesting myths, however, relate to underground personages. The forty-five Grecian Titans, who were of gigantic stature and of proportionate strength, were confined in the bowels of the earth. According to the poets, the flames of Etna proceeded from the breath of Enceladus, and when he turned his weary side the whole island of Sicily was shaken to its foundations. Neptune was not only a god of the oceans, rivers, and fountains, but with a blow of his trident he could create earthquakes at pleasure. The worship of Neptune was established in almost every part of the Grecian world. The Livians, in particular, venerated him, and looked upon him as the first and greatest of the gods. The Palici were born in the bowels of the earth, and were worshipped with great ceremonies by the Sicilians. In a superstitious age the altars of the Palici were stained with the blood of human sacrifices. In Roman mythology, two very familiar deities are Pluto and Vulcan. These and a host of other deities, the outcome of imagination, excited by displays of seismic and volcanic activity, we meet with every day in picture galleries, in museums, in literature, and in our daily papers. The fact that we are enjoined not to make any graven image of that which is in the earth beneath suggests that in the time of Moses a certain form of worship called for some correction. Over and above adding a clause to the decalogue, large earthquakes have in very many ways affected religions. After the earthquake which shook England on April 6, 1580, the then Archbishop of Canterbury drew up a form of prayer which was approved by the Privy Council, and ordered by them to be read in all dioceses in the kingdom. In the world there are many instances of religious services being held on the anniversary of an earthquake, it being regarded as an exhibition of God's vengeance upon a wicked people. The belief that earthquakes are signs or warnings owes its origin in part to prophecies in the Bible, where, for example, we read that "there shall be famines and pestilences and earthquakes" as portending future calamities. Earthquakes have led to the abolition of oppressive taxation, the abolition of masquerades, the closing of theatres, and even to the alteration in fashions. A New England paper, of 1727, tells us that "a considerable town in this province has been so far awakened by the awful providence in the earthquake that the women have generally laid aside their hooped petticoats."

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

The success of the Children's Museum in Bedford Park, Brooklyn, as a factor in education forms the subject of an article by Miss A. B. Gallup in the April number of the *Popular Science Monthly.* At its commencement in 1899 the museum comprised only two rooms, containing little more than a few insects, shells, and stuffed birds. The eagerness with which these were visited by children soon led, however, to extension, and twelve exhibition rooms, furnished with specimens, models, and pictures illustrative of nearly every subject interesting to childhood, are now open to the public. These collections illustrate the chief branches of natural history, geography, art, and the history of the United States. Young people are encouraged to think and act for themselves, one result being the installation of a wireless telegraph apparatus by a party of boy visitors, some of the members of which subsequently obtained appointments as wireless telegraphists. The institution seems worthy of imitation in this country.

Dr. W. E. Hoyle, director of the Manchester Museum, speaking on children's museums at a museum conference